ILLUMINATION OPTICAL SYSTEM AND EXPOSURE APPARATUS

This application claims a benefit of priority based on Japanese Patent Application No. 2003-324639, filed on September 17, 2003, which is hereby incorporated by reference herein in its entirety as if fully set forth herein.

BACKGROUND OF THE INVENTION

The present invention relates generally to an exposure apparatus, and more particularly to an exposure apparatus that uses a light source in an extreme ultraviolet ("EUV") or X-ray region with a wavelength between 10 nm and 200 nm to expose an object, such as a single crystal substrate for a semiconductor wafer, and a glass plate for a liquid crystal display ("LCD").

A reduction projection exposure method that uses, for example, EUV light or X-ray have been proposed as one of methods for manufacturing semiconductor circuit devices having a fine pattern (see, for example, Japanese Patent Application Publication No. 10-70058 (or its U.S. counterpart, U.S. Patent No. 6,504,896B1), Japanese Patent Application Publication No. 2003-045774 (or its U.S. counterpart, U.S. Patent Application Publication No. 2003031017A1), and Japanese Patent

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Application Publication No. 2003-045784 (or its U.S. counterpart, U.S. Patent Application Publication No. 2003031017A1).

This method uses the EUV light to illuminate a mask (or a reticle) that forms a circuit pattern, and projects a reduced size of the pattern on the mask, onto a wafer surface, and to expose photoresist on the wafer surface for pattern transfer.

FIG. 12 schematically shows principal part of a conventional EUV reduction projection exposure apparatus 1000. In FIG. 12, 1001 denotes an EUV light emission point, 1002 denotes EUV light, 1003 denotes a filter, 1004 denotes a first rotational paraboloid mirror, 1005 denotes a reflection integrator, 1006 denotes a second rotational paraboloid mirror, 1007 denotes a reflection mask, 1008 denotes plural mirrors that constitute a projection optical system, 1009 denotes a wafer, 1010 denotes a mask stage, 1011 denotes a wafer stage, 1012 denotes an arc aperture, 1013 denotes a laser light source, 1014 denotes a laser condensing optical system, and 1017 denotes a vacuum chamber. FIG. 14 is a plane view showing a relationship between an illuminated area 1015 on the mask 1007 and an arc area 1016 to be exposed.

The exposure apparatus 1000 thus includes a light source section 1013, 1014 that generates the EUV light, an illumination optical system (*i.e.*, the first

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rotational paraboloid mirror 1004, the reflection
integrator 1005 and the second rotational paraboloid
mirror 1006), the reflection mask 1007, the projection
optical system 1008, the wafer 1009, the mask mounted
5   stage 1010, the wafer mounted stage 1011, an alignment
mechanism (not shown) for precise alignment between
mask and wafer positions, the vacuum chamber 1017 that
maintains vacuum of the entire optical system vacuum
for reduced attenuations of the EUV light, and an
10   exhaust apparatus (not shown).

The illumination optical system uses the first
rotational paraboloid mirror 1004 to condense the EUV
light 1002 from the emission point 1001 into the
reflection integrator 1005 so as to form secondary
15   light sources, and uses the second rotational
paraboloid mirror 1006 to superimpose and condense the
EUV light from these secondary light sources so as to
uniformly illuminate the mask 1007.

The reflection mask 1007 forms a pattern to be
20   transferred, using a non-reflected part made of an EUV
absorber on a multilayer mirror. The projection
optical system 1008 images, on the wafer 1009, the EUV
light that has information of a circuit pattern
reflected by the reflection mask 1007.

25   The projection optical system 1008 is configured
to have excellent imaging performance in an off-axis,
thin arc area (i.e., apart from an optical-axis center).

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The aperture 1012 with the arc opening just prior to the wafer 1009 enables exposure to use only this thin arc area. The exposure scans the reflection mask 1007 and the wafer 1009 simultaneously and transfers a

5 rectangular shot on the entire surface of the mask.

The projection optical system 1008 is comprised of plural multilayer mirrors, and configured to project a reduced size of pattern on the mask 1007 onto the wafer 1009 surface. The projection optical system 1008

10 typically forms an image-side telecentric system, and usually provides an object side (or the reflection mask side) with a non-telecentric structure so as to avoid physical interference with the illumination light incident upon the reflection mask 1007.

15 The laser condensing optical system 1014 condenses a laser beam from the laser light source 1013 onto a target (not shown) at the emission point 1001, generating a high-temperature plasma light source 1001. The EUV light 1002 thermally radiated from this plasma

20 light source is reflected on the first rotational paraboloid mirror 1004 and turns into parallel EUV light. This light is reflected on the reflection integrator 1005 and forms a multiplicity of secondary light sources.

25 The EUV light from these secondary light sources is reflected on the second rotational paraboloid mirror 1006 and illuminates the reflection mask 1007.

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Distances from the secondary light sources to the second rotational paraboloid mirror 1006 and from the secondary rotational paraboloid mirror 1006 to the reflection mask 1007 are set to be equal to a focal distance of the second rotational paraboloid mirror 1006.

Since a focal point of the second rotational paraboloid mirror 1006 is located at positions of the second light sources, the EUV light emitted from the secondary light sources irradiates as parallel light the reflection mask 1007. The projection optical system 1008 is configured to project an image of the secondary light sources onto an entrance pupil surface, and thereby meets the Kohler's illumination conditions. The EUV light that illuminates one point on the reflection mask 1007 is superimposed EUV beams emitted from all the secondary light sources.

The illuminated area 1015 on the mask surface is similar, as shown in FIG. 13, to a plane shape of a concave or convex mirror as an element in the reflection integrator 1005, and it is an approximately rectangular shape that includes the arc shape 1016 to be actually exposed. The projection optical system 1008 is configured to project an image of the secondary light sources onto its pupil surface.

However, the conventional EUV reduction projection exposure apparatus has been disadvantageous, because

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the aperture 1012 that defines an illuminated area is provided near the wafer 1009 and should be somewhat apart from the driving wafer during exposure. This separation defocuses the exposure area.

It is conceivable to provide a similar aperture near the reflection mask 1007, but the same problem occurs. The problem would be serious because the similar aperture should be located near the reflection mask 1007 so that it does not shield necessary light incident upon and exiting from the reflection mask.

It is also conceivable to provide an imaging system between a reticle and an aperture for defining the illuminated area, its detailed structure has not been conventionally clarified.

BRIEF SUMMARY OF THE INVENTION

Accordingly, with the foregoing conventional problems in mind, it is an exemplary object of the present invention to provide an exposure apparatus, which clarifies an imaging system between an reticle and an aperture for defining an illuminated area, and includes an illumination optical system that has the imaging system.

In order to achieve the above object, an exposure apparatus of one aspect according to the present invention includes an illumination optical system for

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illuminating a pattern of a reflection mask, by using

light from a light source, wherein the illumination

optical system includes a field stop that defines an

illuminated area on the reflection mask, and has an

5   opening, and an imaging system for directing the light

from the opening in the field stop into the reflection

mask, the imaging system being a coaxial optical system,

and a projection optical system for projecting the

pattern on the reflection mask onto a substrate,

10   wherein a principal ray of the imaging system at a side

of the reflection mask forming an inclination angle to

a common axis of the coaxial optical system, the

inclination angle being approximately equal to an angle

between a principal ray of the projection optical

15   system at the side of the reflection mask and a normal

to a surface of the reflection mask.

      Other features and advantages of the present

invention will be apparent from the following

description taken in conjunction with the accompanying

20   drawings, in which like reference characters designate

the same or similar parts throughout the figures

thereof.

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BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles

5   of the invention.

FIG. 1 is a schematic view of an embodiment according to the present invention.

FIG. 2 is a view of an integrator that receives parallel light.

10   FIG. 3A is a schematic view of a reflection integrator having plural convex cylindrical surfaces, and FIG. 3B is a schematic view of a reflection integrator having plural concave cylindrical surfaces.

FIG. 4 is a view of a sectional shape of the

15   integrator.

FIG. 5 is a view for explaining an angular distribution of light reflected on a cylindrical surface.

FIG. 6 is a view showing an arc area formed by the

20   light reflected on the cylindrical surface.

FIG. 7A is a view in a scan exposure start state, and FIG. 7B is a view in a scan exposure end state.

FIG. 8 is a schematic view of a variable arc slit and a masking blade.

25   FIG. 9 is a view showing actions of the masking blade during scan exposure.

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FIG. 10 is a schematic view of a masking imaging system.

FIG. 11A is a view showing an aperture stop corresponding to a large σ mode in a normal illumination, FIG. 11B is a view showing an aperture stop corresponding to a small σ mode in a normal illumination, FIG. 11C is a view showing an aperture stop corresponding to an annular illumination mode, and FIG. 11D is a view showing an aperture stop corresponding to a quadrupole illumination mode.

FIG. 12 is a schematic view of a prior art illustration.

FIG. 13 is a schematic perspective view of a conventional reflection integrator.

FIG. 14 is a view of a conventional illuminated area and an arc area to be exposed.

FIG. 15 is a flowchart for explaining a method for fabricating devices (semiconductor chips such as ICs, LSIs, and the like, LCDs, CCDs, etc.).

FIG. 16 is a detailed flowchart for Step 4 of wafer process shown in FIG. 15.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will now be described in detail in accordance with the accompanying drawings.

5   FIRST EMBODIMENT

FIG. 1 is a schematic view of an embodiment according to the present invention. As illustrated, 1 denotes an excitation laser beam. 2 denotes a plasma emission point. 3a denotes a nozzle that injects a

10   liquid drop as a target for plasma generations, and 3b denotes a liquid-drop recovery part for recovering and recycling liquid drops that have not received excitation laser beam. 4 denotes a condenser mirror that receives light emitted from the plasma emission

15   point. 6a denotes a filter that removes flying particles (or debris) from the plasma, and 6b denotes a wavelength filter that removes light other than the EUV light. 7 denotes a pinhole aperture arranged at or near the condensed point of the condenser mirror 4. 8

20   denotes a vacuum chamber that accommodates the plasma light source. These elements constitute a light source section. 5 denotes the EUV light condensed by the mirror 4. 9 denotes a connector that connects an exposure apparatus body to a plasma light source

25   section in a vacuum state.

10a and 10b are part of a parallelizing optical system that receives the EUV light through the aperture

7, converts it into parallel light, and includes a
concave mirror and a convex mirror. 11a is an
integrator having plural cylindrical mirrors, and 11b
and 11c are part of an optical system that includes a
rotational paraboloid mirror for condensing the light
from the integrator 11a into an arc shape. 12, 13
constitute a slit system (or a field stop) wherein 12
denotes a slit that has an arc opening and a partially
variable width. 13 denotes a masking blade for
restricting the illumination light to a desired exposed
area, located on a surface conjugate to the reflection
mask 16. 14 denotes a masking imaging system that
images at a desired magnification with respect to the
masking blade 13 as the object side and the reflection
mask 16 as the image side, and forms an arc illuminated
area on the reflection mask. 14a, 14b, 14c and 14d,
respectively, denote a curved mirror in the masking
imaging system 14, and 14e is a plane mirror that
reflects light from the imaging system 14 to 14d to
reflect the image-side light 14' of the masking imaging
system 14 for entry into the reflection mask 16 at a
predetermined angle. 15 denotes an aperture stop
located at a pupil surface in the masking imaging
system 14a to 14d. These elements constitute an
illumination optical system for illuminating the
reflection mask 16 with light from the light source
section.

17 denotes a mask stage that holds the reflection
mask 16. 18 denotes a projection optical system that
includes plural mirrors, forms a coaxial optical system,
and provides an object side with non-telecentricity and
5   an image side with telecentricity. 19 denotes a wafer
that applies a photosensitive material. 20 denotes a
wafer stage that holds the wafer 19, and 21 denotes a
vacuum chamber that maintains the entire optical system
in the vacuum atmosphere for reduced attenuation of the
10 EUV light.

The high power excitation pulse laser beam 1,
emitted from the excitation laser part that includes an
excitation laser light source and condenser optical
system (not shown), is configured to condense at a
15 position of the emission point 2, and forms a plasma
light source section. The liquid drop as the target of
this laser plasma light source, such as Xe, is
configured to be continuously injected at regular time
intervals from the nozzle 3a, and pass the condensed
20 point 2. When the thus-injected liquid drop is located
at the position of the element 2, the excitation pulse
laser beam 1 irradiates liquid drops to generate the
high-temperature plasma from the emission point 2, and
the thermal radiation from this plasma generates the
25 EUV light.

While the instant embodiment uses Xe liquid drops
as a target, the target may use Xe gas injected into a

vacuum, a cluster generated from an adiabatic expansion, solidified Xe gas that has been cooled on the metal surface, and a metal tape, such as Cu. Alternatively, the EUV light source can use an undulator, or a so-

5   called discharge method, such as Z pinch method, a plasma focus, a capillary discharge, and hollow cathode triggered Z pinch.

The EUV light irradiated from the plasma emission point 2 is condensed by the condenser mirror 4, such as

10   a rotational spheroid mirror, and taken out as a EUV. beam. The filter 6a removes flying particles (or debris) that fly ahead directly from the plasma and its vicinity, and the filter 6b removes an unnecessary wavelength component for the EUV exposure, as required.

15   Then, the light is condensed into the pinhole aperture 7 provided on a boundary surface between the vacuum chamber 8 that accommodates the plasma light source, and the vacuum chamber 21 that accommodates the exposure apparatus body. The connector 9 connects the

20   vacuum chamber 8 that accommodates the light source to the vacuum chamber 21 that accommodates the exposure apparatus body.

The EUV light 5 that has passed through the aperture 7 is converted into approximately parallel

25   light 10' by the parallelizing optical system that includes a concave mirror 10a that has an opening at its center, and a convex mirror 10b that has a smaller

diameter than the concave mirror 10a. Here, the

concave mirror 10a has an opening for light reflected

by the convex mirror 10b, and its opening is located on

the optical axis of the EUV light from the light source.

5   These mirrors 10a and 10b have a reflective surface of

approximately rotational symmetry with respect to the

optical axis of the EUV light from the light source.

The center axis approximately accords with the optical

axis of the EUV light.

10   The above condenser mirror 4, and the mirrors 10a

and 10b form a reflective multilayer for effectively

reflect the EUV light, and become at high temperature

during exposure since they absorb the radiant energy

from the high-temperature plasma 2. Therefore, they

15   are made of a material with high thermal conductivity,

such as metal, and have cooling means (not shown), such

as water cooling, for continuous cooling during

exposure.

Although not described specifically, a reflective

20   surface of each mirror in the optical system forms a

reflective multilayer to effectively reflect the EUV

light, and the mirror can be made of a material with

high thermal conductivity, such as metal, as required.

The EUV light 10' that has been converted into

25   approximately parallel light enters the integrator 11a

that has plural reflective cylindrical mirrors, and the

plane mirror 11b and the rotational paraboloid mirror

11c condense, into an arc shape, divergent beams divided by each cylindrical surface, thereby forming an arc illuminated area that has uniform light intensity distribution on the opening in the arc slit 12.

5   A detailed description will now be given of how the integrator 11a uniformly illuminates the arc area, with reference to another figure.

FIG. 3A is a typical perspective view of the reflection convex cylindrical integrator 11a having

10   plural convex cylindrical surfaces which receives parallel light, and the approximately parallel EUV light 10' enters in the illustrated direction. FIG. 3B is a typical perspective view of a reflection concave cylindrical integrator having plural concave

15   cylindrical surfaces that exhibit similar effects to FIG. 3A. The integrator 11a in FIG. 1 is a reflection convex cylindrical integrator, as shown in FIG. 3A, but it may be a reflection concave cylindrical integrator shown in FIG. 3B or a combination thereof.

20   FIG. 4 is a typical sectional view of the reflection convex cylindrical integrator, FIG. 5 is a view for explaining reflections of the EUV light on the cylindrical surface of the reflection convex cylindrical integrator, and FIG. 6 is an angular

25   distribution diagram of the EUV light reflected the reflection convex cylindrical integrator. In each

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figure, reference numeral 11a denotes the reflection convex cylindrical integrator.

As shown in FIG. 3A, when approximately parallel EUV light 11 is incident upon the integrator 11a having plural cylindrical surfaces, the secondary light source is formed near the integrator surface and the EUV light radiated from this secondary light source has a cone angular distribution. Then the arc illumination is available by reflecting the EUV light on the mirror that has a focal point at a position of this secondary light source, and illuminating the reflection mask or a surface conjugate with the reflection mask.

In order to explain operations of the reflection integrator having plural cylindrical surfaces, a description will now be given of a behavior of the reflected light when the parallel light is incident upon one cylindrical mirror with reference to FIG. 5. It is now supposed that parallel light is incident upon one cylindrical surface at an angle θ to a surface perpendicular to the center axis.

When a ray vector of the incident parallel light is defined as P1 = (0, $-\cos\theta$, $\sin\theta$), and a normal vector on the cylindrical reflective surface is defined as n = ($-\sin\alpha$, $\cos\alpha$, 0), the ray vector of the reflected light becomes P2 = ($-\cos\theta$ x $\sin2\alpha$, $\cos\theta$ x $\cos2\alpha$, $\sin\theta$). The plotted ray vector of the reflected light in a phase space forms a circle with a radius of

cosθ on an xy plane, as shown in FIG. 6. Therefore, the reflected light becomes cone divergent light, and the secondary light source is located on a vertex of this cone surface. When the integrator 11a has a

5   concave cylindrical surface, this secondary light source exists as a real image outside the reflective surface, whereas when the integrator has a convex cylindrical surface, this secondary light source exits as a virtual image inside the reflective surface. As

10   shown in FIG. 4, when the reflective surface is limited to part of the cylindrical surface and has a center angle of 2Φ, the ray vector P2 exists as an arc 601 having a center angle of 4Φ on the xy plane as shown in FIG. 6.

15   Then, suppose a rotational paraboloid mirror having a focal distance f and a focal point at the secondary light source's position that is formed as a result of parallel light incident upon the above cylindrical mirror, and an illuminated surface located

20   apart from this mirror by the distance f. The secondary light source emits the cone divergent light, which is then reflected on the mirror having the focal distance f and then converted into parallel light. The reflected light is a sheet beam having an arc section

25   with a radius f x cosθ and a center angle of 2Φ. Therefore, as shown in FIG. 6, only the arc area 601 is

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illuminated with a radius of f x cosθ and a center angle of 2Φ on the illuminated surface.

The foregoing description refers to one cylindrical mirror. Referring now to FIG. 2, a description will be given of the integrator 11a that arranges a multiplicity of cylindrical surfaces in parallel on a large area, and receives the parallel light 10′ with a certain beam diameter in a direction shown in FIG. 1.

In FIG. 2, 11a is the above integrator, 11b is a plane mirror, 11c is a rotational paraboloid mirror, and 12 is a slit having an arc opening. The rotational paraboloid mirror 11c is a mirror that is centrically symmetrical around a shaft 201AX, and has a reflective surface that is part of a surface formed by rotating a paraboloid having a focal point 202 around an axis 201AX. A distance between the focal point 202 and the mirror effective part's center point 204 is the focal distance f. A distance between the point 204 and the arc slit 12 is set to be approximately equal to the focal distance f.

The rotational paraboloid mirror 11c is arranged so that its rotational axis 201AX is arranged parallel to the reflective surface on or near the reflective surface of the integrator 11a, and aligned with the cylindrical surfaces. As illustrated, the plane mirror 11b is located between the effective part's center

point 204 and the focal point 202 on the rotational paraboloid mirror 11c, the point 202' that is symmetrical to the focal point 202 with respect to the reflective surface of the mirror 11b can be located

5 approximately at a center position of the reflective surface's effective part on the integrator 11a. In other words, an optical path length from the position 204 to the position 202' is equal to the focal distance f.

10 This arrangement provides the position 202' and the arc slit 12 with a separation by the focal distance f from the rotational paraboloid mirror 11b or a relationship of the Fourier conversion surface. Therefore, the approximately parallel EUV light 10'

15 incident upon the integrator 11a as illustrated is condensed at or near the opening of the arc slit 12.

The EUV light to the rotational paraboloid mirror 11c has a low incident angle ξ of the primary ray between 0° and 45°, more specifically, 20°. Thereby,

20 the defocus amount reduces when light is condensed in the arc slit 12 and condensing efficiency improves near the arc opening rather than the high incident angle. Thereby, the optical loss due to shielding reduces, and the illumination system's efficiency improves.

25 Since the light reflected on the mirror that arranges plural cylindrical surfaces in parallel has the same angular distribution as the above, the arc

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area is illuminated with a radius $f \times \cos\varepsilon$ near the arc

slit 12, where ε is a light incident angle to the

integrator 11a. Since the light incident upon one

point near the arc slit 12 results from the entire

5   illuminated area that arranges plural cylindrical

surfaces in parallel, the angular range γ, *i.e.*,

condensing NA, becomes $\gamma = D / f$, where D is a beam

diameter of the approximately parallel EUV light 10'.

In this case, the arc illuminated area maintains

10   uniform light intensity since the multiple cylindrical

surfaces on the integrator 11a superimpose the light.

In other words, this can achieve effective and uniform

arc illumination.

Turning back to FIG. 1, a description will be

15   given of the exposure apparatus of the instant

embodiment. As illustrated, the masking blade 13

partially restricts the arc illuminated area formed

near the opening in the arc slit 12, and the masking

imaging system 14 enlarges or reduces the arc

20   illuminated area at a desired magnification. As a

consequence, the reflection mask 16 is illuminated with

an arc shape by introducing the arc illuminated area at

a desired incident angle into the reflection mask 16

held by the mask stage 17. The center of curvature of

25   the arc illuminated area accords with the optical axis

18AX of the projection optical system 18.

The circuit pattern is exposed when the projection optical system 18 projects, onto the wafer 19 that applies a photosensitive material, at a magnification suitable for exposure, the reflected EUV light having

5   circuit pattern information from the reflection mask 16 that has been illuminated in an arc shape.

The above wafer is fixed on the wafer stage 20, which serves to provide back and forth and up and down parallel movements on the paper surface under control

10   of distance measuring equipment, such as a laser interferometer (not shown). The scan exposure over the entire surface requires, for example, the reflection mask 16 to be scanned at a speed v in a direction parallel to the paper surface and the wafer 19 to be

15   simultaneously synchronously scanned at a speed v / M in the direction parallel to the paper, where M is a magnification of the projection optical system 18.

The projection optical system 18 is comprised of plural multilayer reflective mirrors, and provided with

20   excellent imaging performance in an off-axis, thin arc area. The projection optical system 18 is configured to project a reduced size of the pattern on the mask 16 onto the wafer 19 surface, and form an image-side (or wafer-side) telecentric system. The projection optical

25   system 1008 provides an object side (or the reflection mask side) with a non-telecentric structure so as to avoid physical interference with the illumination light

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incident upon the reflection mask 16, and the instant
embodiment inclines the image-side principal ray, for
example, by about 6° relative to the normal direction
of the mask 16.

5   A detailed description will now be given of (1)
scan exposure using the arc illumination, (2) a method
of correcting uneven exposure by using the arc slit 12,
(3) operations of the masking blade 13 during the scan
exposure, and (4) a structure of a masking imaging
10   system in this order.

FIGs. 7A and 7B show scan exposure start and end
states on the wafer surface, respectively. As
illustrated, 701 denotes an arc illuminated area on the
wafer surface. 702 denotes an exposed area as an
15   object to be exposed. In this figure, the exposure
area 702 moves from left to right on the paper when the
wafer stage is driven. The arc illuminated area 701 is
configured to relatively scan the exposed area 702.
The masking blade works so that the arc illuminated
20   area 701 is prevented from illuminating part except for
the exposure area 702 at the exposure start and
exposure end. This will be described in the operation
of the masking blade.

The above is applicable to scan exposure in a
25   relatively reverse direction to the scanned direction
in this embodiment.

A detailed description will be given of a method
of correcting an uneven exposure with the arc slit 12
in the above scan exposure. As illustrated, 810
denotes a multiple movable edges for partially changing
5   a slit width 811 in the arc slit 12.   811 denotes a
slit opening for forming the arc illuminated area. 812
denotes an arc illuminated area formed by the above
integrator 11a and mirror system 11b and 11c, and this
illuminated area defines light that passes through the
10   slit opening 811.

The uneven exposure occurs if there is uneven
light intensity in the arc slit when the scan exposure
transfers a reduced size of the circuit pattern in the
reflection mask 16 onto the wafer 19. One solution for
15   this problem uses a drive system (not shown) to move
the movable edges 810 to narrow only the slit width
that provides relatively strong light intensity in the
arc slit, and to reduce the light amount for the scan
exposure by a desired amount. As a result, exposure
20   with uniform intensity is available on the entire
exposed surface as a result of accumulation.

The masking blade 13 includes four light-shielding
plates 801, 802, 803 and 804, the upper and lower
light-shielding plates 803 and 804 shield light at both
25   ends of the arc illuminated area 812 in the arc slit
opening 812, and define a longitudinal width (or a scan
width) of the exposed area 702 shown in FIG. 7A.

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The light-shielding plates 801 and 802 define a
lateral width (or a scan length) in the exposed area
702 by moving in a lateral direction and opening and
closing an aperture from the exposure start to the
exposure end for one shot in the scan exposure, as
described in detail below, with reference to FIG. 9.

In FIG. 9, (A1) to (A5) time-sequentially
represent scan exposure from a start to an end, while
(B1) to (B5) show actions of light-shielding plates 801
and 802 in the masking blade 13 at states (A1) to (A5).

The exposure is about to start at the state (A1),
and the light-shielding plate 802 starts to move to the
right at the state (B1) to open the aperture. The arc
illuminated area 701 is light-shielded in this state,
and not actually illuminated although illustrated.
When the scan exposure starts as shown in (A2), the
light-shielding plate 802 moves as shown in the state
(B2) so as to light-shield a projection the arc
illuminated area 701 from the exposure area 702. As
shown in (B3), the arc illuminated area 701 moves
within the exposed area 702 for scan exposure, the
light-shielding plate 802 moves to the right as shown
in (B3) to completely open the slit opening 811. When
the scan exposure nearly ends as shown in (A4), the
light-shielding plate 801, in turn, moves to the right
so as to light-shield a projection of the arc
illuminated area 701 from the exposed area 702. When

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the scan exposure ends as shown in (A5), the light-shielding plate 801 moves and completely shields the slit opening 811. The above series of actions provides the scan exposure for a desired exposed area.

5   Next follows a detailed description of the masking imaging system 14 with reference to FIG. 10. The masking imaging system 14 is an imaging optical system that uses the above masking blade 13 as an image surface, and the reflection mask 16 (at a position 102

10   in the figure) as an image surface, and includes reflective multilayer mirrors. This imaging system is a coaxial optical system that serves to image and form an arc illuminated area suitable for the projection optical system 18 by applying a desired magnification

15   to the object-side arc area that arranges the common axis (or optical axis) 10A nearly at a center.

       As illustrated, 14a, 14b, 14c and 14d are concave or convex spherical or aspheric mirrors that use the center axis 10AX for rotational symmetry, and are

20   concave, concave, convex and concave from 14a in the instant embodiment. The pupil surface in the masking imaging system 14 is located on or near the reflective surface of the mirror 14b, at which the aperture stop 15 is located. The aperture stop 15 changes its

25   opening pattern to change a convergent angle (or a so-called coherence factor σ) of the illumination light at

the reflection mask side, or to provide modified

illumination, as described in detail below:

The EUV light condensed at a position of the

masking blade 13 arranged near the arc slit 12 enters

5   the masking imaging system 14 while the principal ray

is parallel to or object-side telecentric to the

rotationally symmetrical axis 10AX. The incident light

condenses into the image surface 102 through the above

four mirrors and aperture stop 15. Notably, the image

10   side has a non-telecentric structure, and an incident

angle 101 upon the image surface 102 of the principal

ray 103 (or an angle between the principal ray 103 and

the rotationally symmetrical axis 10AX) is set to be

approximately equal to the inclination angle of the

15   object-side principal ray of the projection optical

system 18 to the mask-surface normal. In other words,

an angle between the mask-side principal ray of the

imaging system 14a to 14d and the rotationally

symmetrical axis 10AX, corresponding to each position

20   on the reflection mask's illuminated area is set to be

approximately equal to an angle between the mask-side

principal ray of the projection optical system and the

normal to the mask surface. The instant embodiment

sets the incident angle 101 to be about 6°, equal to

25   the angle between the mask-side principal ray of the

projection optical system 18 and the normal to the mask

surface. Since the optical axis 18X of the projection

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optical system is parallel to the normal to the mask

surface, an angle between the optical axis 18X of the

projection optical system and the mask-side principal

ray of the projection optical system 18. Therefore,

5   the angle between the mask-side principal ray of the

imaging system and the optical axis of the imaging

system is approximately equal to the angle between the

angle between the mask-side principal ray of the

projection optical system and the normal to the mask

10   surface. The imaging surface properly corrects defocus

at the image side, and the spot diameter on the image

surface is designed to be 5 mm or smaller, preferably 1

mm or smaller.

When the plane mirror 14e reflects the image-side

15   light 14' of the masking imaging system 14 shown in FIG.

1 and angles it toward the reflection mask 16, an

orientation of an arc illuminated area formed by the

light 14' is reversed and the arc's center accords with

an intersection between the center axis 18AX of the

20   projection system 18 and the reflection mask. The

above incident angle 101 enables the principal ray of

the light 14' to approximately accord with the

principal ray of the object-side light 18' of the

projection optical system 18 with respect to a

25   reflective surface on the reflection mask.

A description will now be given of a method for

varying a coherent factor σ and for providing a

modified illumination, such as annular illumination, by switching the aperture stop 15 in the masking imaging system 14. The aperture stop 15 (or a pupil surface in the masking imaging system) and the pupil surface of

5 the projection optical system 18 are conjugate with each other. Therefore, an opening pattern or a light transmission pattern in the aperture stop 15 corresponds to a light-source image on the projection optical system's pupil surface or an effective light

10 source distribution. FIGs. 11A to 11D are views of exemplary opening shapes of the aperture stop 15. A stop in FIG. 11A has a circular opening and corresponds to a large σ mode in a normal illumination. A stop in FIG. 11B has a circular opening smaller than the stop

15 in FIG. 11A and corresponds to a small σ mode in a normal illumination. A stop in FIG. 11C has an annular opening and corresponds to the annular illumination mode. A stop in FIG. 11D has four openings and corresponds to the quadrupole illumination mode.

20 It is possible to switch to a desired opening shape by preparing several opening patterns, for example, on a turret, and by rotating this turret using an aperture stop drive system (not shown). Instead of using the turret, other mechanical methods may be used,

25 such as switching of plural aperture stops that are linearly arranged or use of an iris stop.

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SECOND EMBODIMENT

A description will now be given of an embodiment of a device fabricating method using the exposure apparatus of the first embodiment. FIG. 15 is a manufacture flow for explaining a fabrication of devices (*i.e.*, semiconductor chips such as IC and LSI, LCDs, CCDs, etc.). Here, a description will be given of a fabrication of a semiconductor chip as an example. Step 1 (circuit design) designs a semiconductor device circuit. Step 2 (mask fabrication) forms a mask having a designed circuit pattern. Step 3 (wafer making) manufactures a wafer using materials such as silicon. Step 4 (wafer process), which is referred to as a pretreatment, forms actual circuitry on the wafer through photolithography using the mask and wafer. Step 5 (assembly), which is also referred to as a post-treatment, forms into a semiconductor chip the wafer formed in Step 4 and includes an assembly step (*e.g.*, dicing, bonding), a packaging step (chip sealing), and the like. Step 6 (inspection) performs various tests for the semiconductor device made in Step 5, such as a validity test and a durability test. Through these steps, a semiconductor device is finished and shipped (Step 7).

FIG. 16 is a detailed flow of the above wafer process. Step 11 (oxidation) oxidizes the wafer's surface. Step 12 (CVD) forms an insulating film on the

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wafer's surface. Step 13 (electrode formation) forms electrodes on the wafer by vapor disposition and the like. Step 14 (ion implantation) implants ion into the wafer. Step 15 (resist process) applies a

5   photosensitive material onto the wafer. Step 16 (exposure) uses the exposure apparatus of the first embodiment to expose a circuit pattern on the mask onto the wafer. Step 17 (development) develops the exposed wafer. Step 18 (etching) etches parts other than a

10   developed resist image. Step 19 (resist stripping) removes disused resist after etching. These steps are repeated, and a circuit pattern is formed on the wafer.

Use of the manufacture method of the instant embodiment would be able to manufacture highly

15   integrated devices, which have been difficult to be manufactured.

While the above embodiments describe the illumination system that uses the EUV light of 13.5 nm, the present invention is applicable to another

20   illumination optical system that uses different light, for example, light in an EUV or E-ray region with a wavelength between 10 nm and 200 nm. No glass material is applicable as a lens for light with a wavelength between 20 and 50 nm, and the optical system should

25   include mirrors only. Therefore, the present invention is effectively applicable to the illumination optical system that uses this region.

As many apparently widely different embodiments of the present invention can be made without departing from the sprit and scope thereof, it is to be understood that the invention is not limited to the

5   specific embodiments thereof except as defined in the claims.